Directly Imaged Companions: Planets or Brown Dwarfs?

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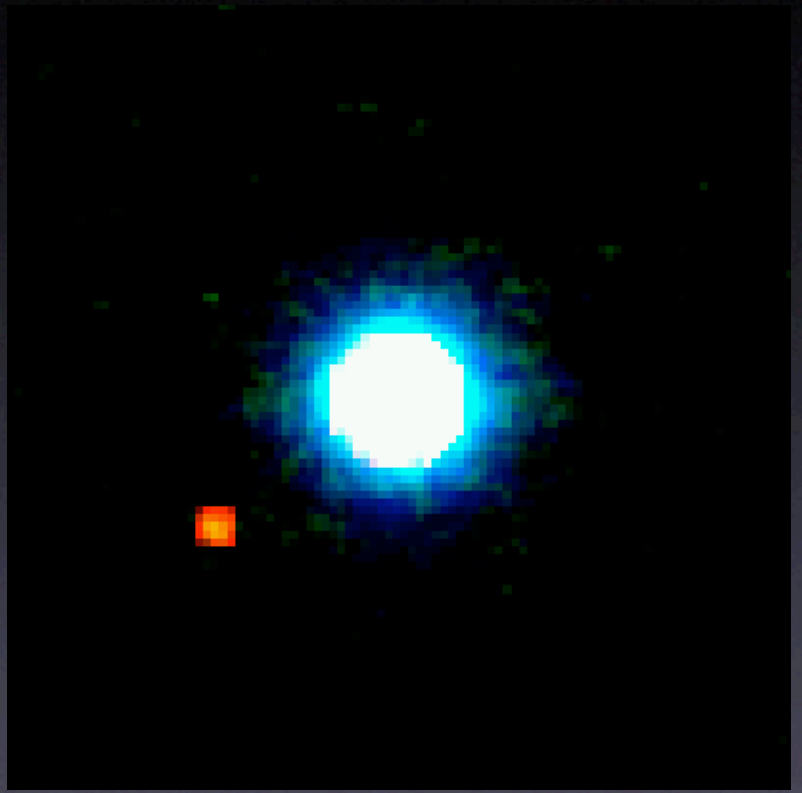
2M1207 Companion

- Companion to ~M8 brown dwarf in TW Hydrae (age ~ 8 Myr)
- red J-K implies late L, T_{eff} ~ 1250 K
- Models give $M = 5 \pm 2\ M_{Jup}$



Chauvin et al. (2004)

Source	SpT	Age (Myr)	J (mag)	H (mag)	K (mag)	L′ (mag)
2MASSWJ1207334−393254	M8	8^{+4}_{-3}	13.00 ± 0.03 [a]	12.39 ± 0.03 [a]	11.95 ± 0.03 [a]	11.38 ± 0.10 [b]
giant planet candidate	L5-L9.5		≥ 18.5 [a]	18.09 ± 0.21 [a]	16.93 ± 0.11 [a]	15.28 ± 0.14 [b]

OPEN **BBC News in video and audio**

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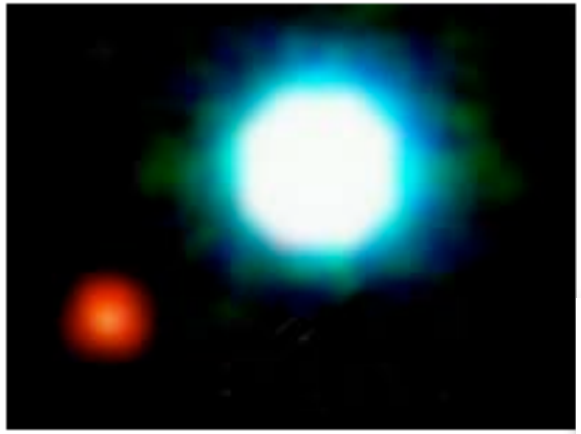
Planet 'seen' around distant sun

European and American scientists say they have photographed a planet outside the Solar System for the first time.



The planet (left) is about five times the mass of our Jupiter

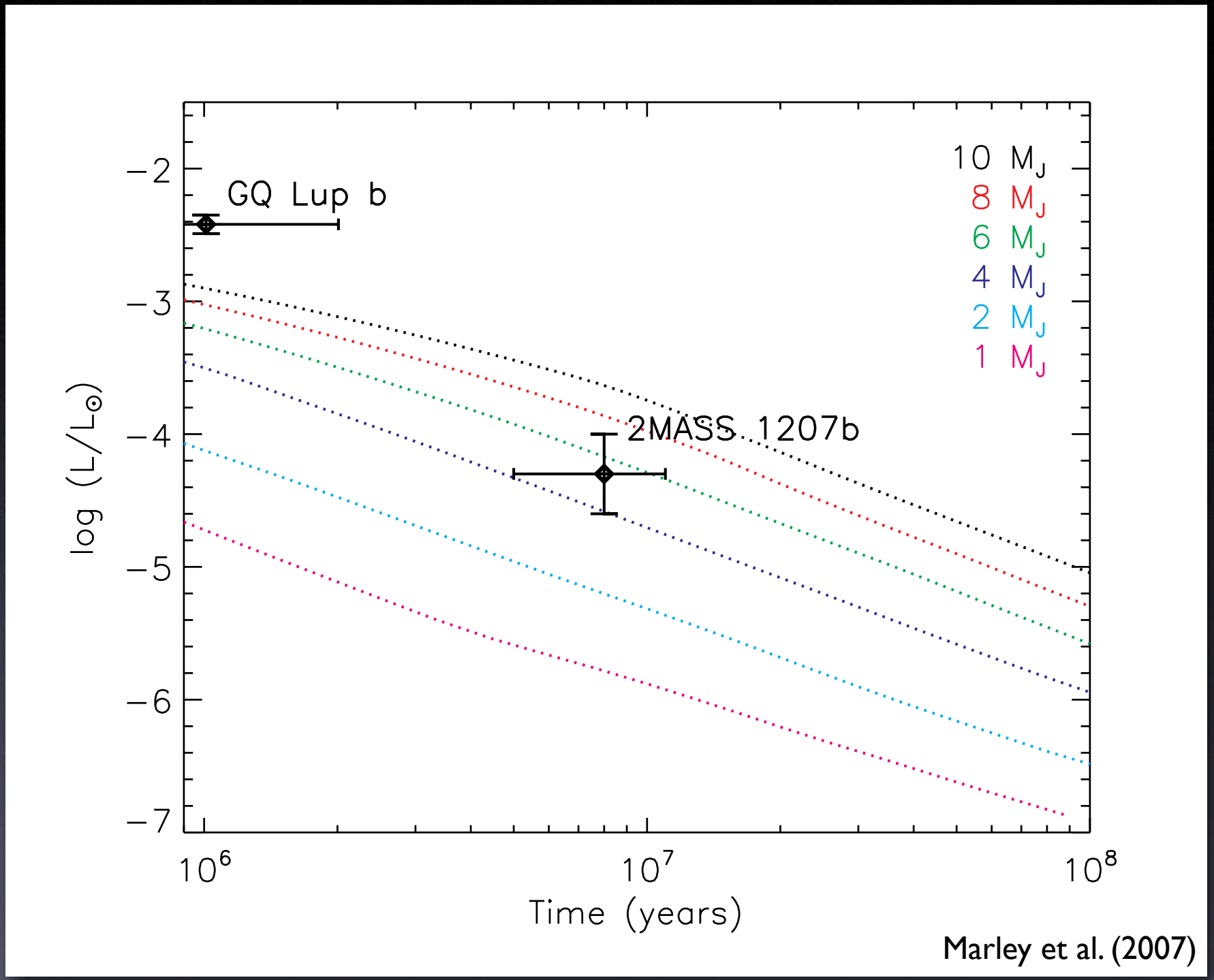
The European Southern Observatory group said the red image is the first direct shot of a planet around another star.

The planet, known as 2M1207b, is about five times the mass of Jupiter and is orbiting at a distance nearly twice as far as Neptune is from our Sun.

Dr Chauvin added: "Given the rather unusual properties of the 2M1207 system, the giant planet most probably did not form like the planets in our Solar System."

"Instead it must have formed the same way our Sun formed, by gravitational collapse of a cloud of gas and dust."

- Is this model mass correct?
- Is planethood just about mass?



Marley et al. (2007)

But is it a planet?

What is a Star?

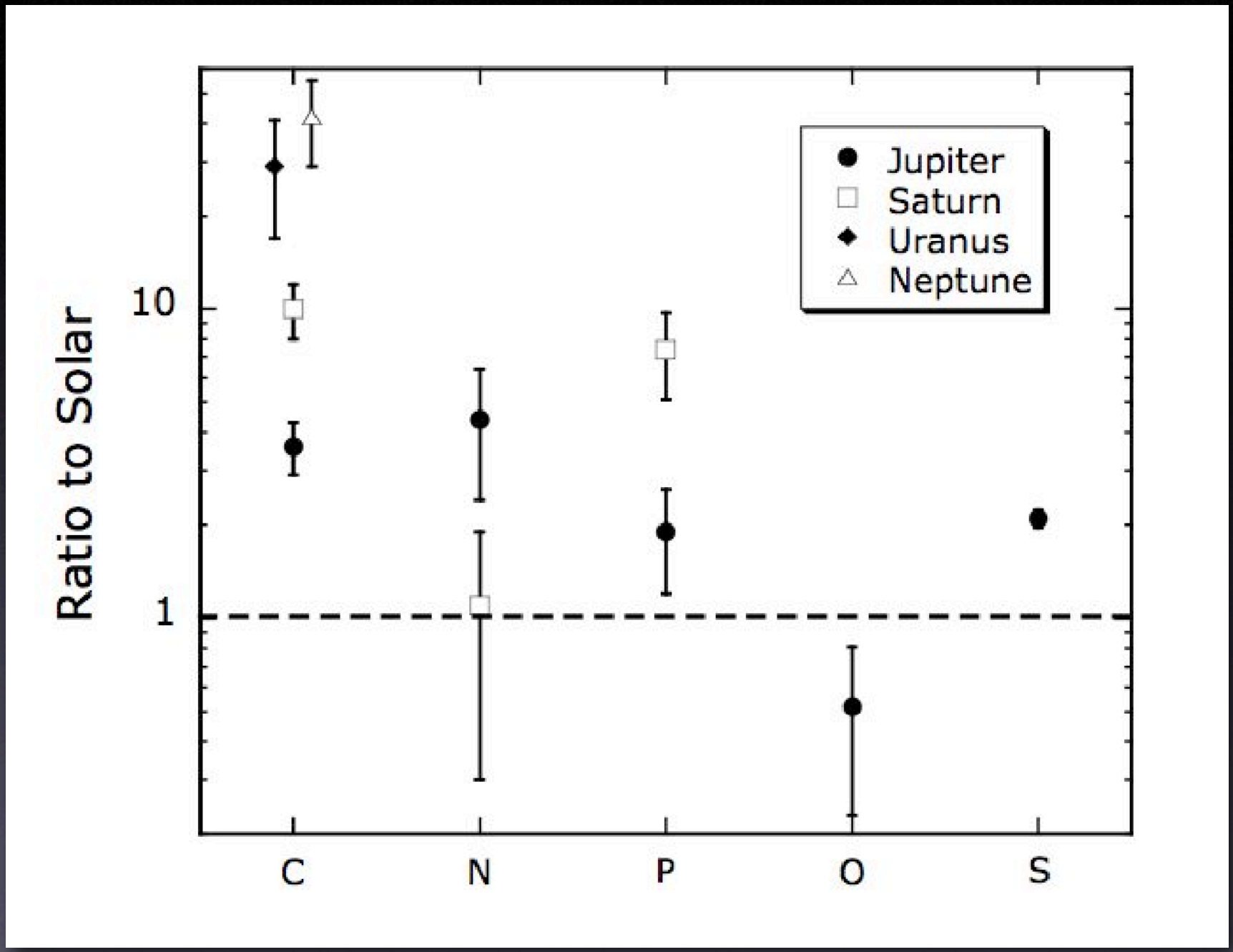
Asked how he became a star, Mr. Carson once replied, "I started in a gaseous state and then I cooled."

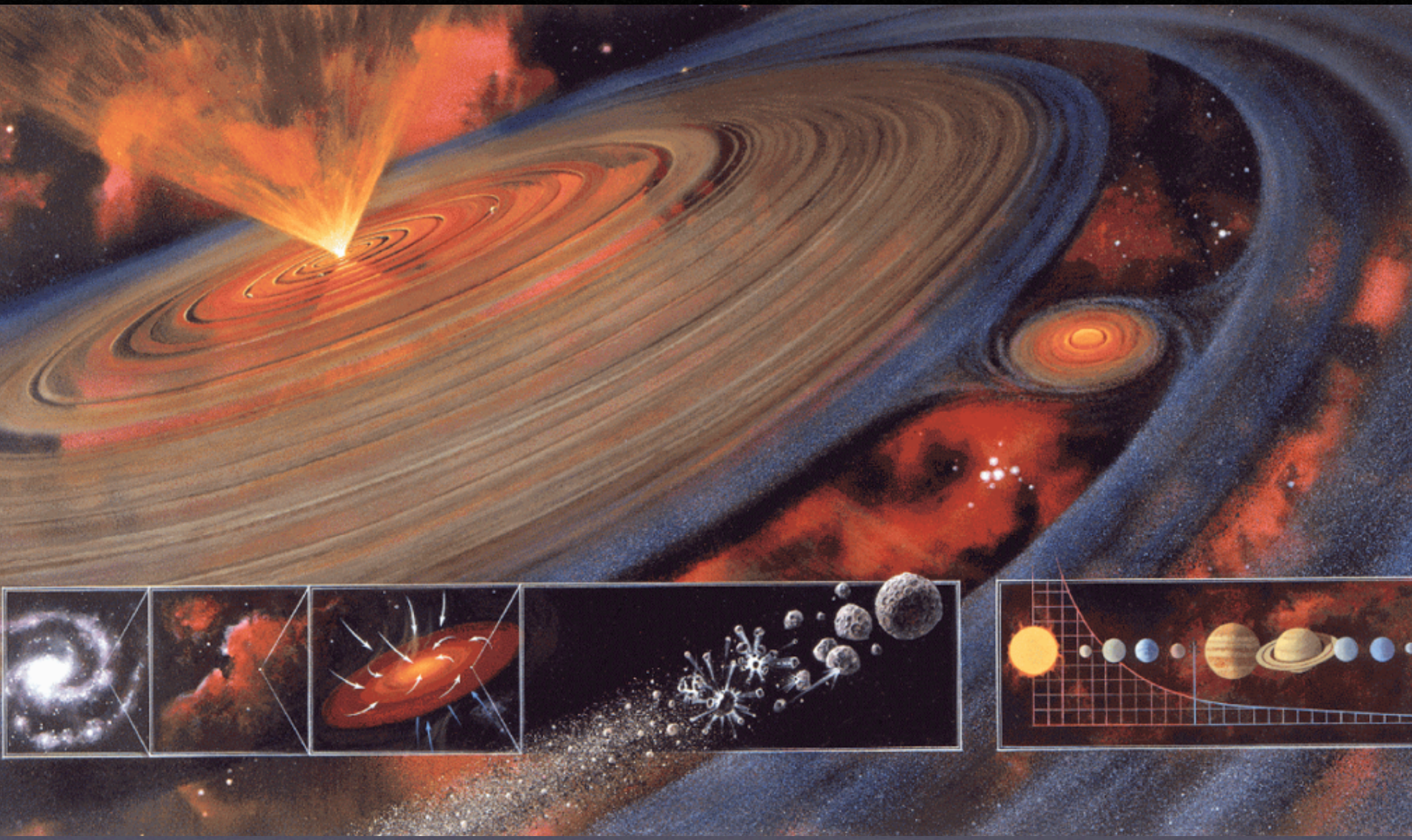
New York Times 1/24/05

Imaged Companions Formed Like Stars

- star formation works down to few M_J
- wide binary fraction: BDs same as stars
- disk fraction similar
- reflect composition of star forming region
- see Chabrier et al. chapter in PPV

Planets are Different


Ratio to Solar
10
1
Jupiter
Saturn
Uranus
Neptune
C
N
P
O
S



Planets differ meaningfully in composition from their primary.

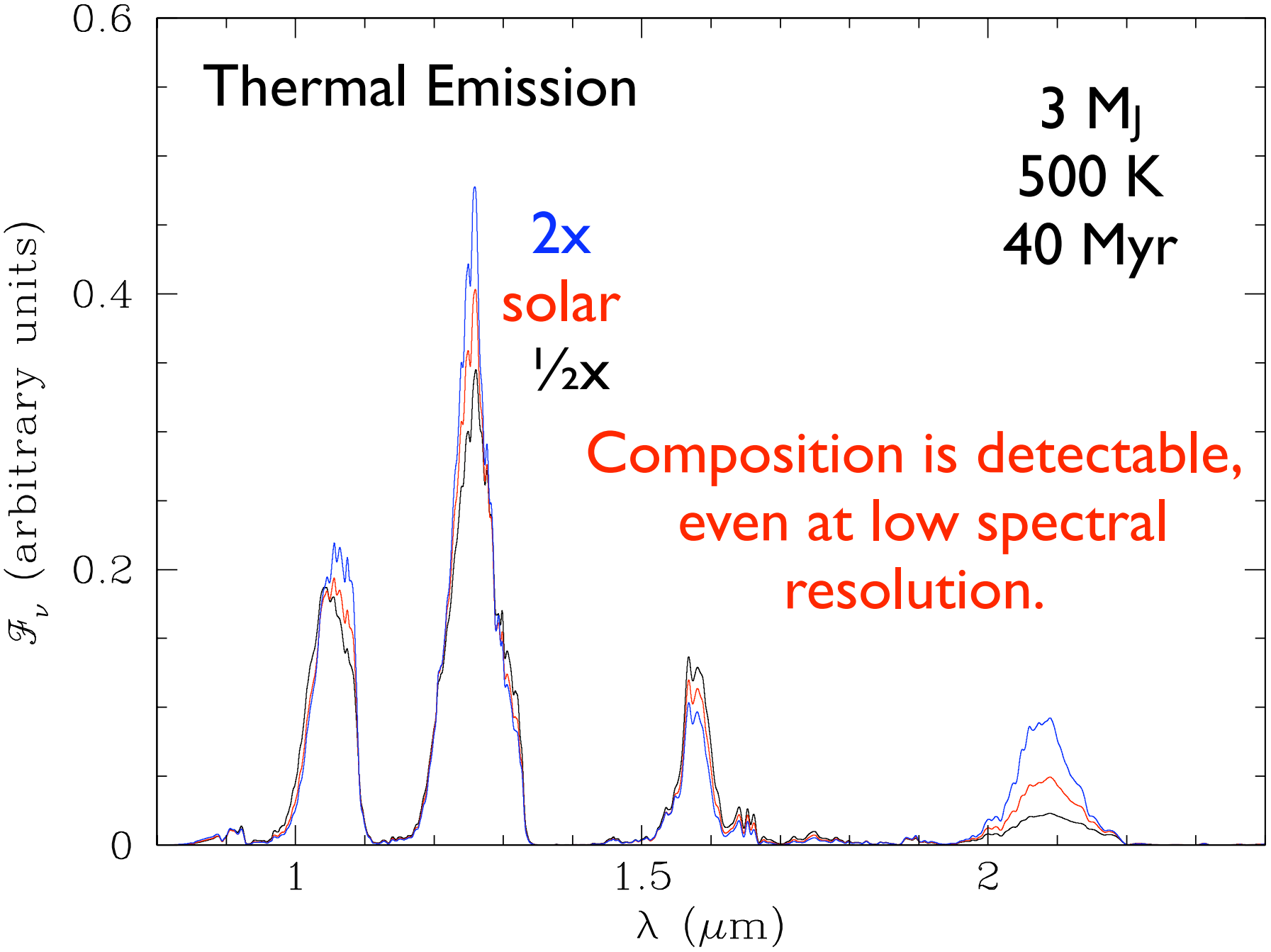
Planethood is About More Than Mass

"Planets" form by secondary processes in a disk surrounding their parent star.

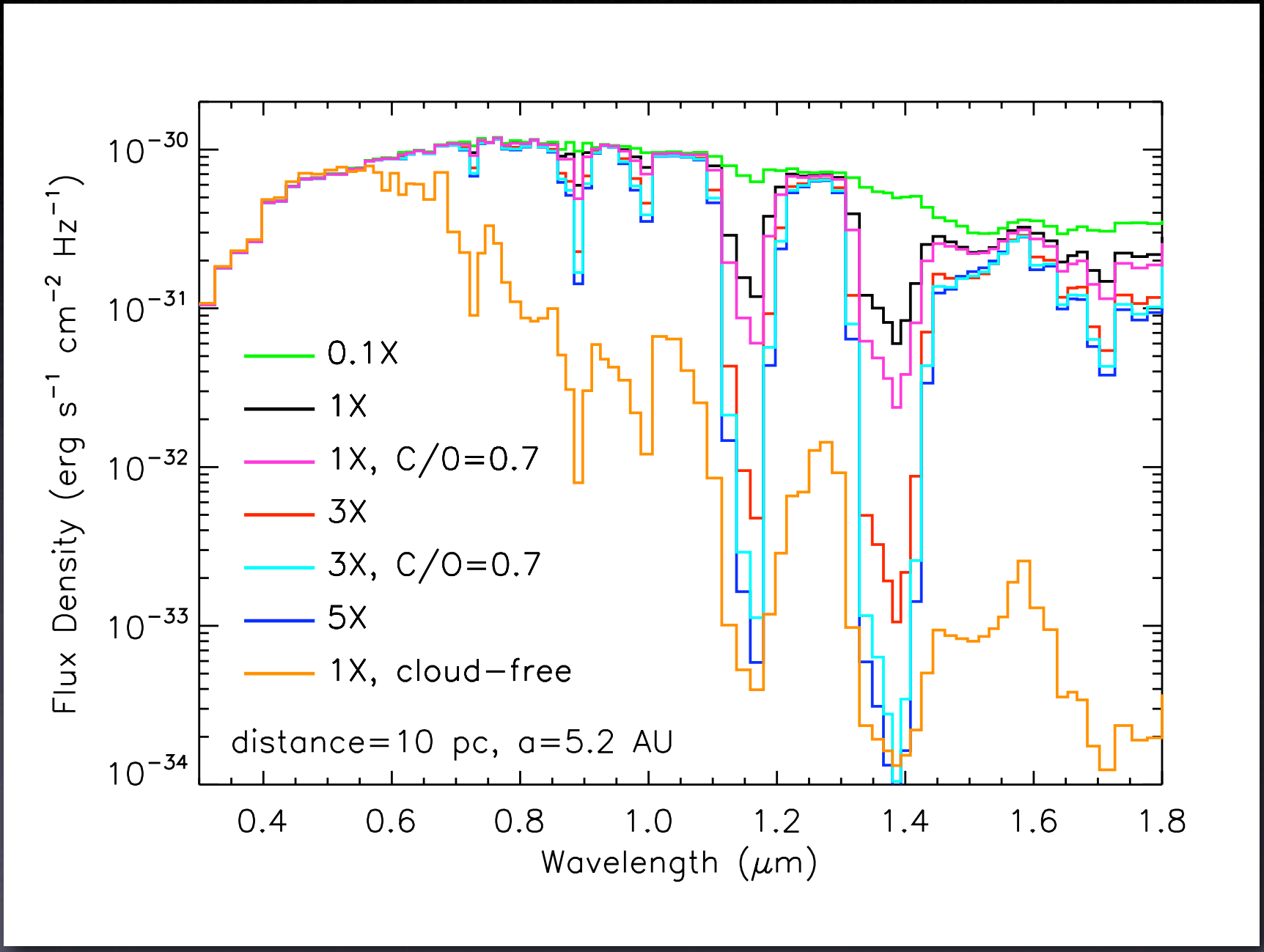
These processes leave compositional and evolutionary fingerprints.

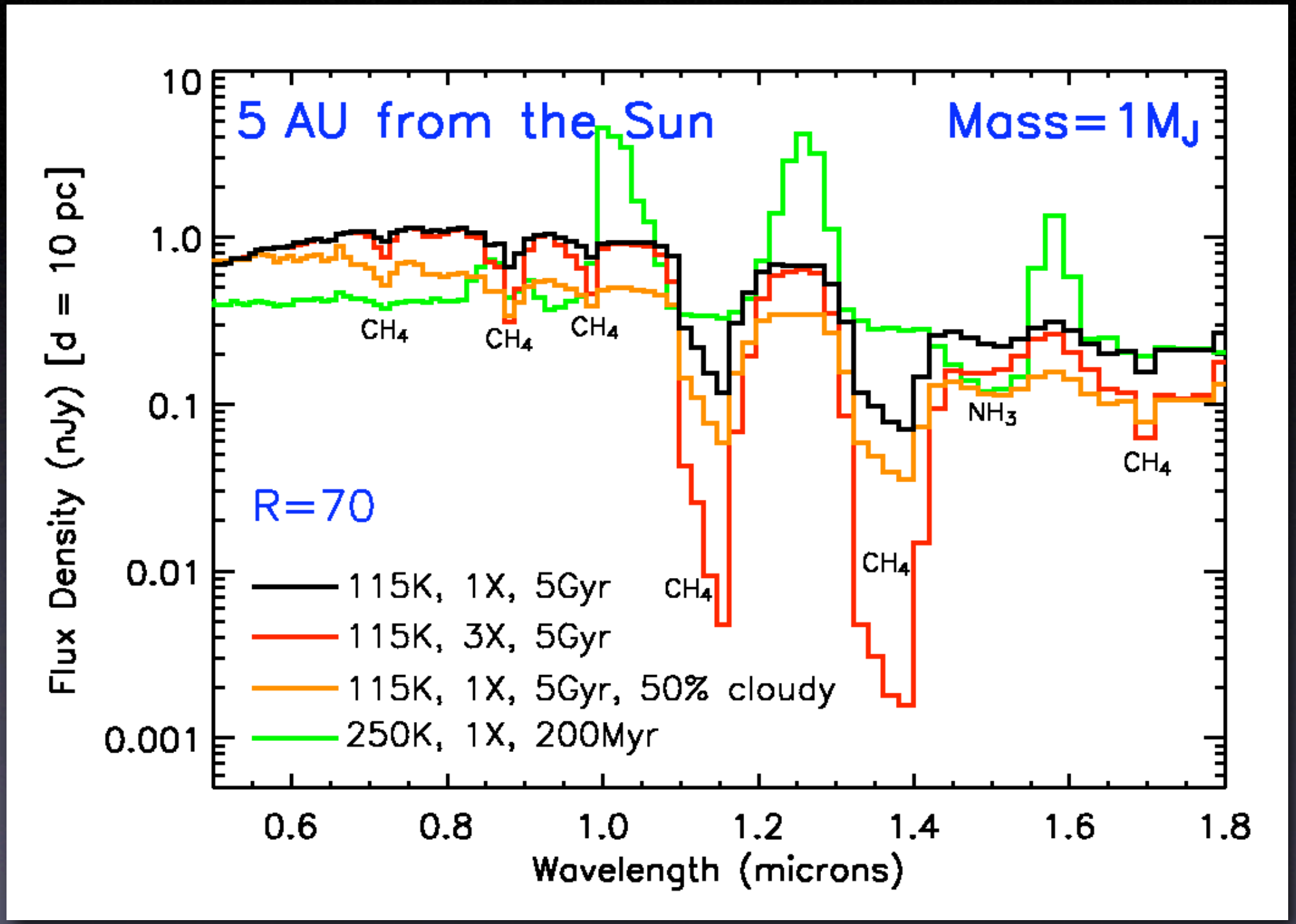
13 M_J deuterium burning limit is meaningless. Nature can make low mass fragments.

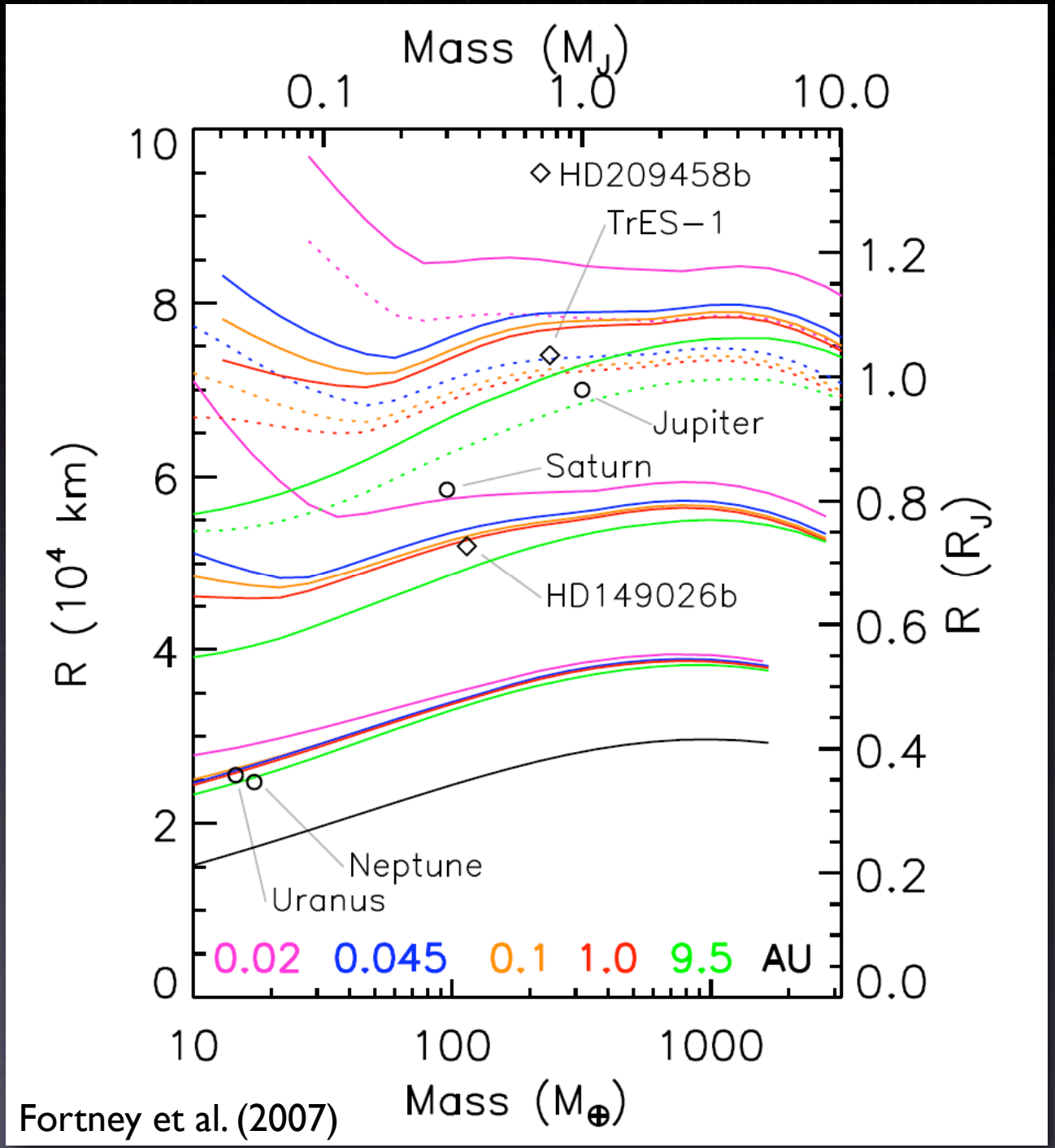
Compositional differences are detectable.


Thermal Emission
3 M_J
500 K
40 Myr
2x
solar
½x
Composition is detectable, even at low spectral resolution.
0.6
0.4
0.2
0
1
1.5
2
$\mathcal{F}_\nu$ (arbitrary units)
λ (μm)

Also in Reflected Light




5 AU from the Sun
Mass=1M$_J$
R=70
Flux Density (nJy) [d = 10 pc]
Wavelength (microns)
10
1.0
0.1
0.01
0.001
0.6
0.8
1.0
1.2
1.4
1.6
1.8
CH$_4$
CH$_4$
CH$_4$
CH$_4$
CH$_4$
NH$_3$
CH$_4$
115K, 1X, 5Gyr
115K, 3X, 5Gyr
115K, 1X, 5Gyr, 50% cloudy
250K, 1X, 200Myr



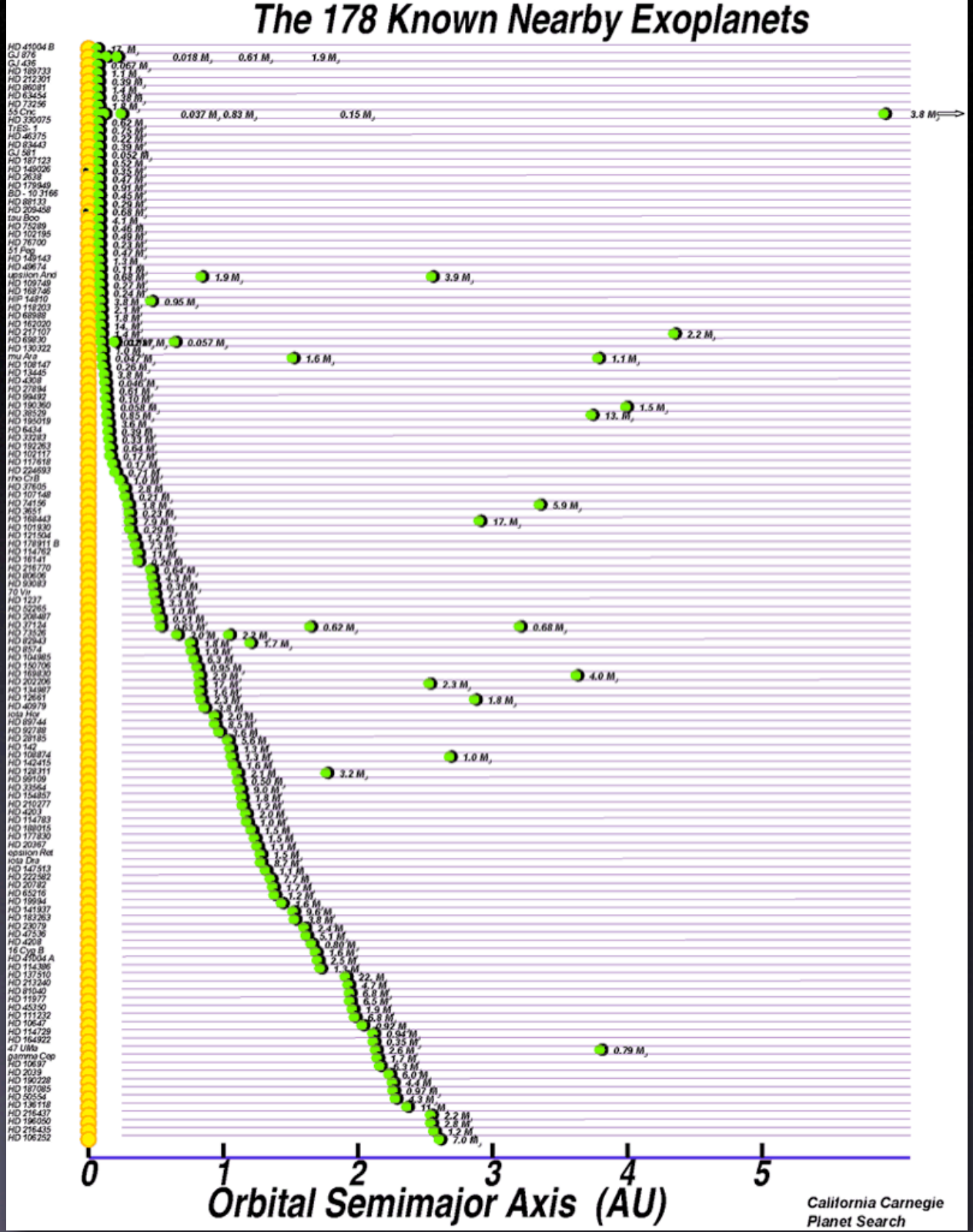
Fortney et al. (2007)

Giant planet radii, obtainable from transit or TPF-C + TPF-I, yield bulk composition and provide observable tests of planethood.

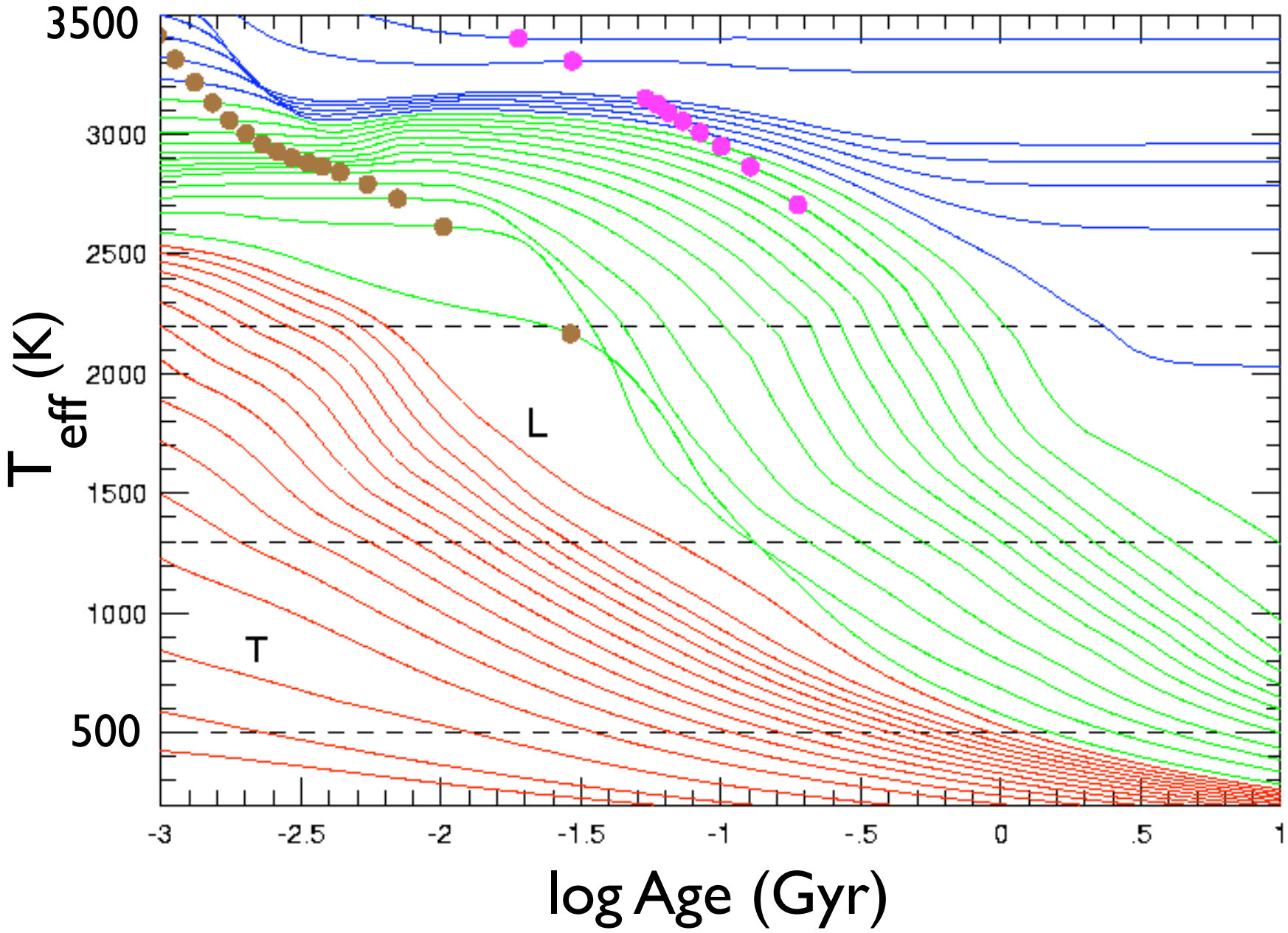
But...

Requiring compostion information sets a higher bar and turns most of the "Known Exoplanets" into "Known Exoplanet Candidates"

Known Exoplanets: HD149026b

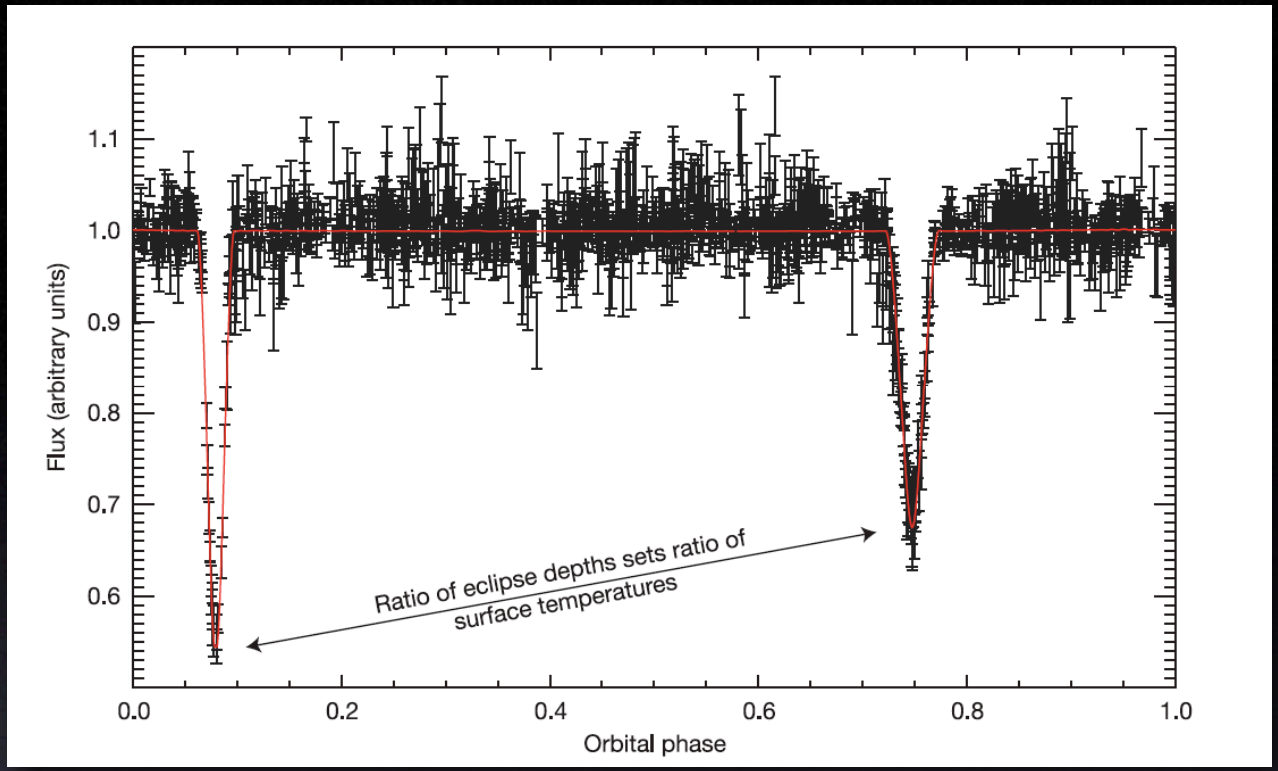


Planets remember their formation mechanism.



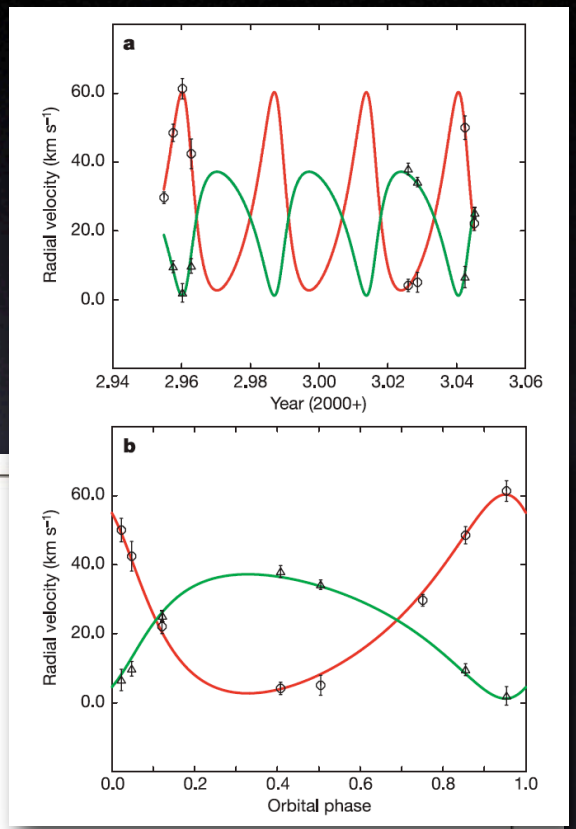
Burrows et al. 1997

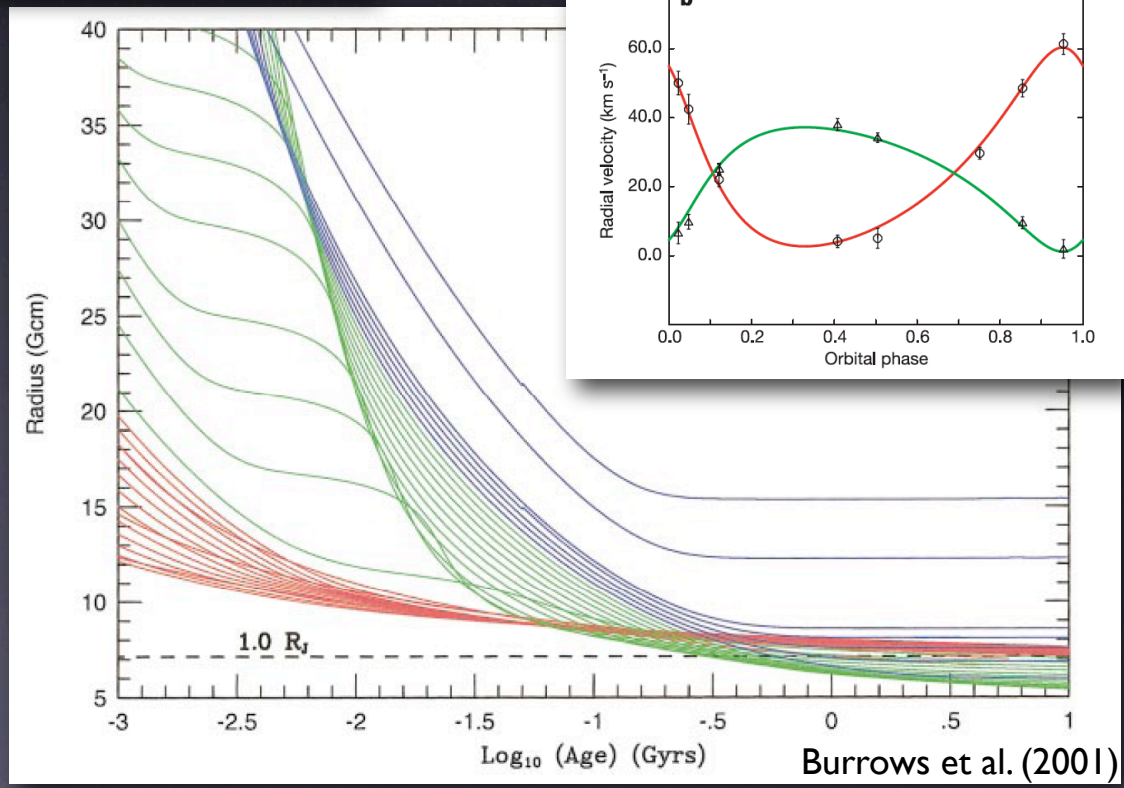
2M0535
eclipsing binary in Orion
age "few 10^6 years"



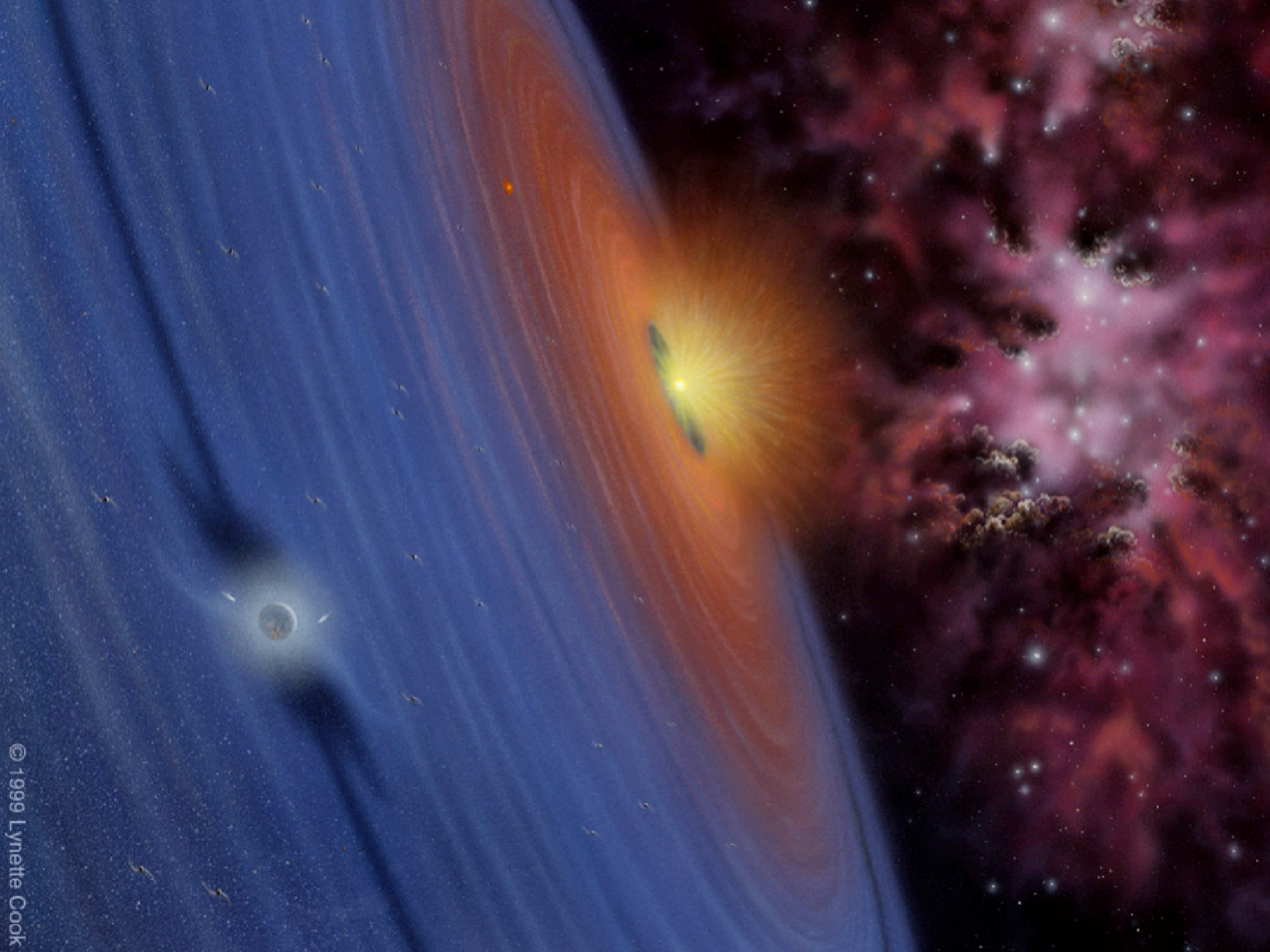
Stassun et al. (2006)

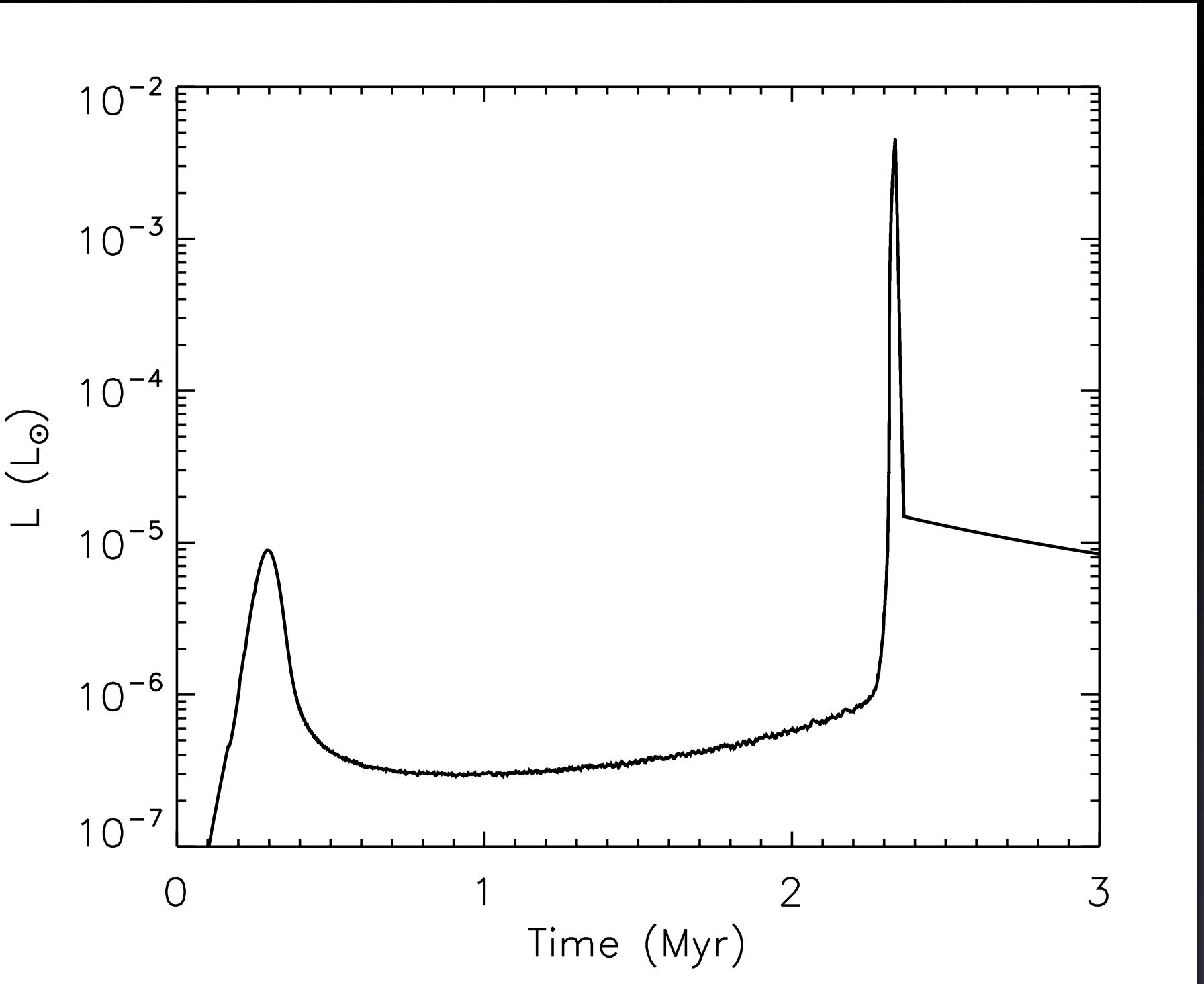
M_1	54 ± 5 M_J
M_2	34 ± 3 M_J
R_1	6.5 R_J
R_2	5.0 R_J

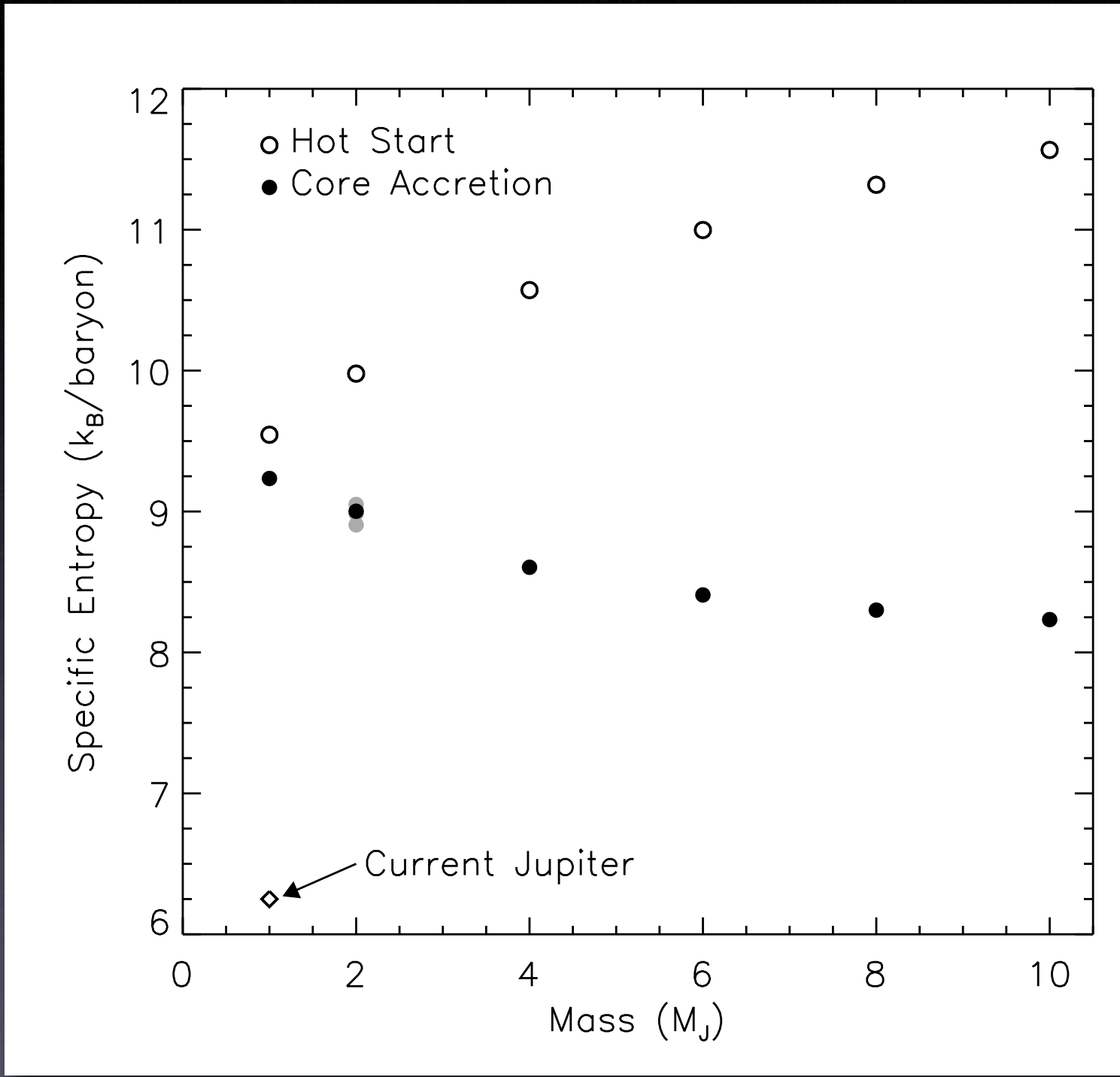


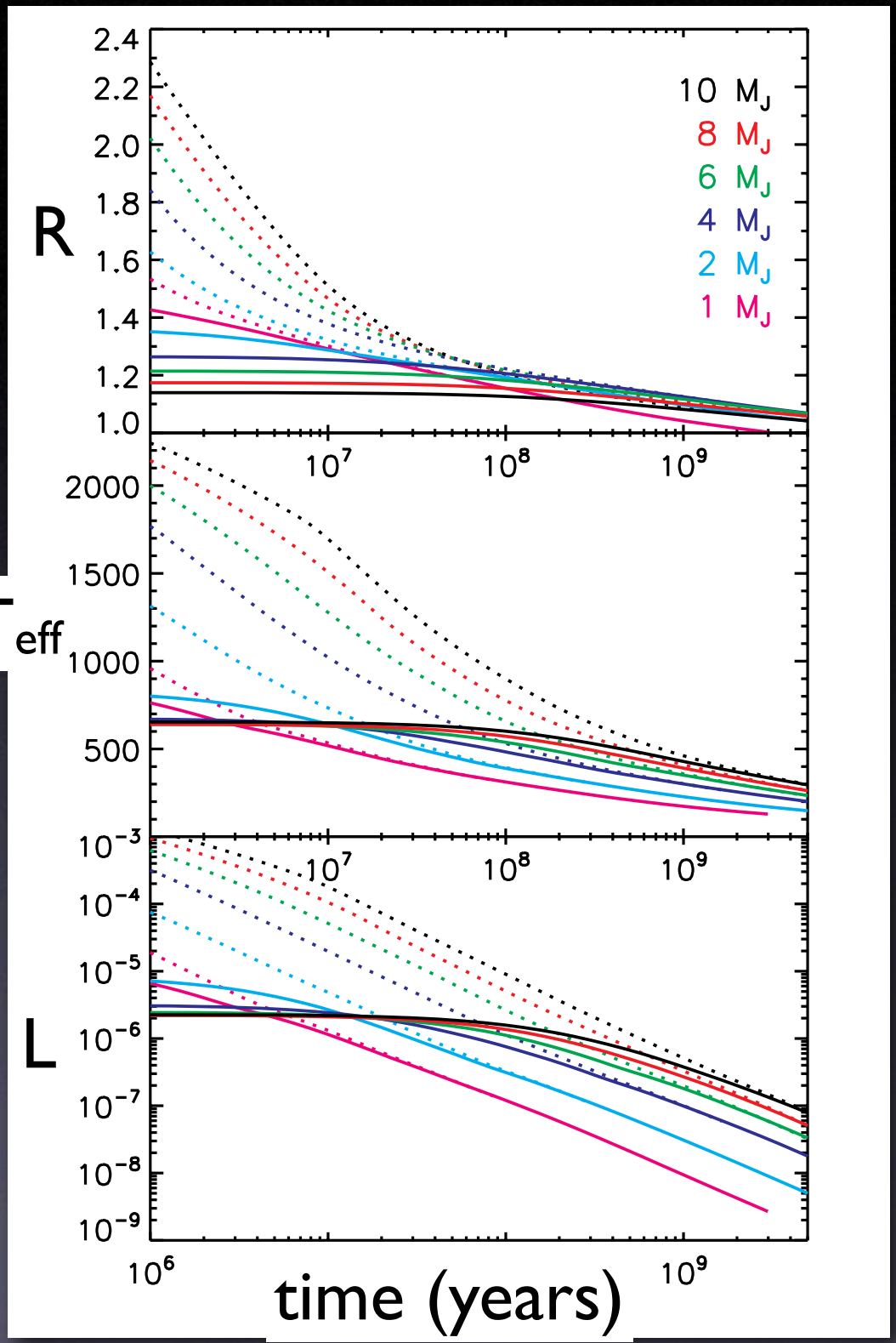


Burrows et al. (2001)


© 1999 Lynette Cook


10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
L ($L_\odot$)
0
1
2
3
Time (Myr)


Hot Start
Core Accretion
Current Jupiter
Specific Entropy (k_B/baryon)
Mass (M_J)
12
11
10
9
8
7
6
0
2
4
6
8
10



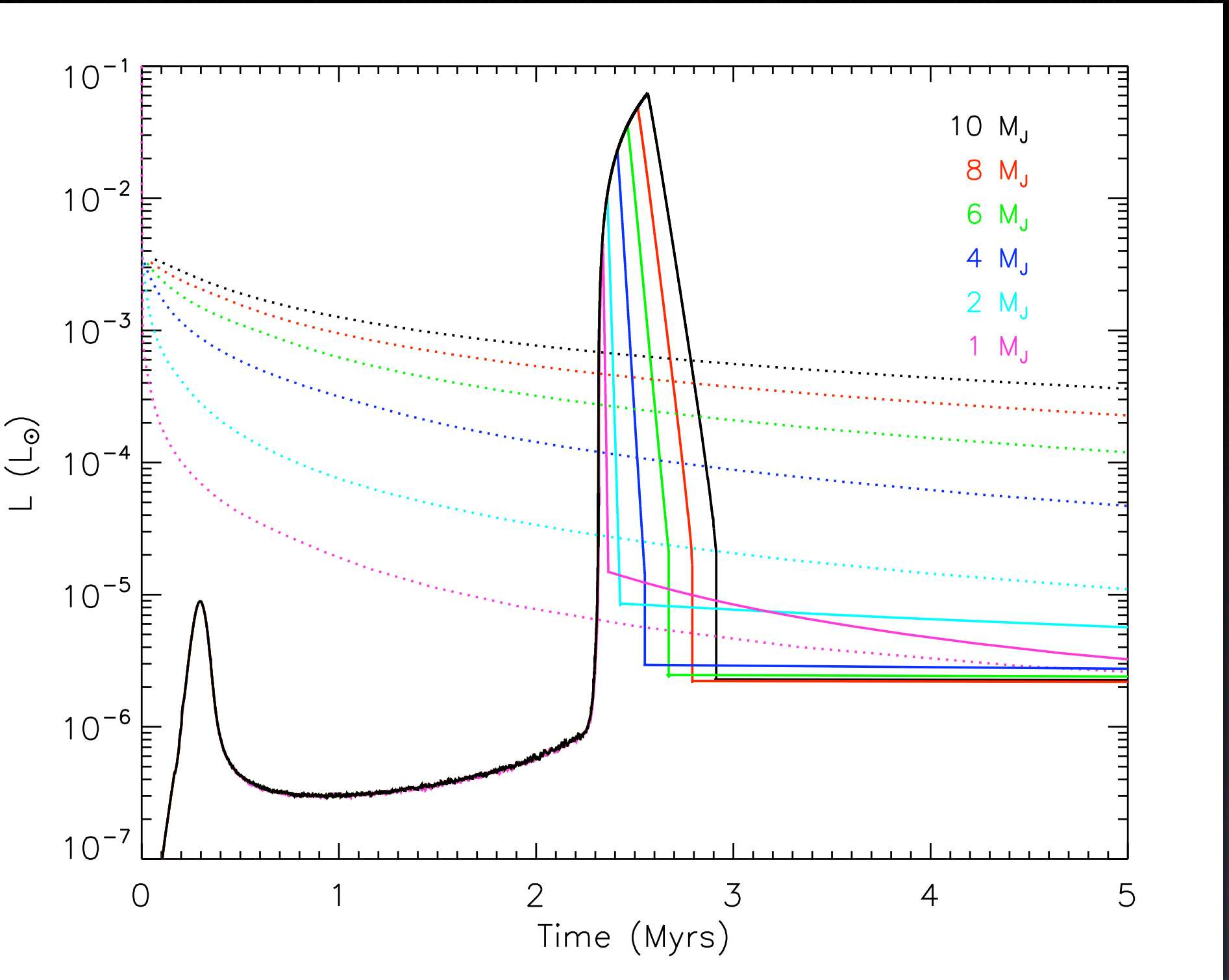
Core Accreted Planets:

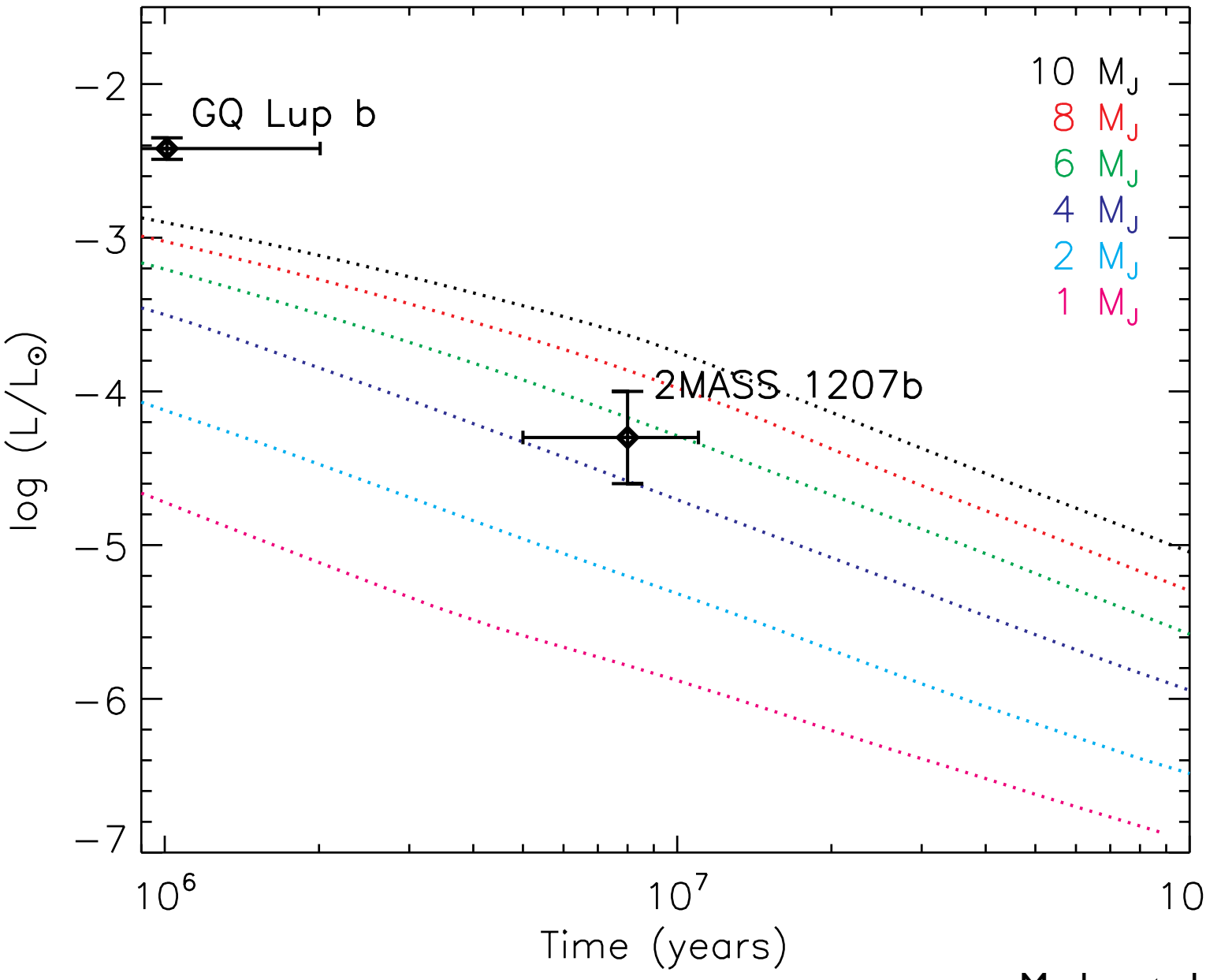
Smaller

Cooler

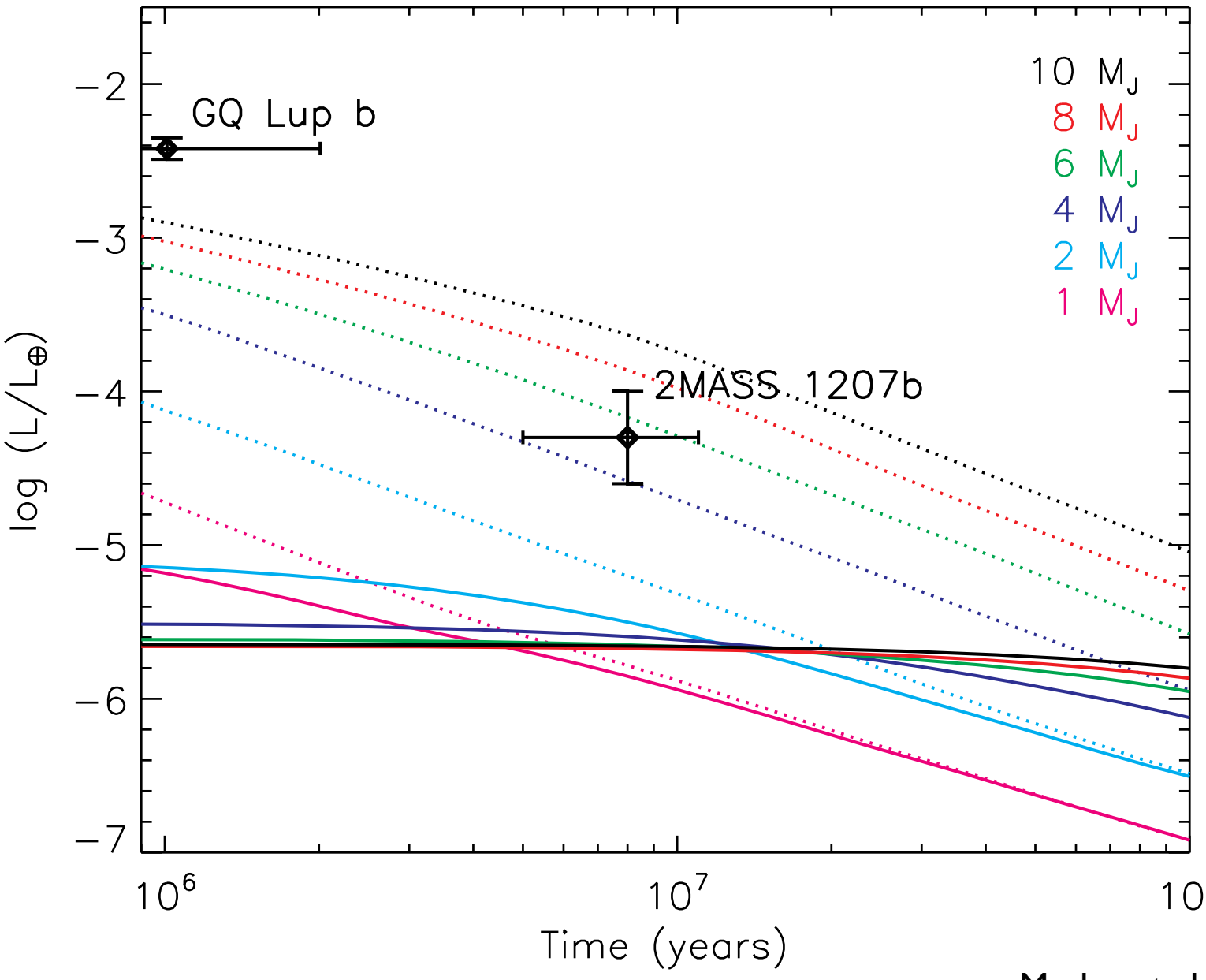
Fainter

Marley et al. (2007)


10 M_J
8 M_J
6 M_J
4 M_J
2 M_J
1 M_J
L (L⊙)
Time (Myrs)
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
0
1
2
3
4
5



Marley et al. (2006)



Marley et al. (2006)

Core Accreted Giants

- Model luminosity depends on treatment of accretion shock
- Many uncertainties (geometry, energy partioning, disk) remain
- Baseline model suggests ***young Jupiters are much fainter than expected***
- Discrepancy increases with mass
- See Marley et al. (2007)

Young Brown Dwarfs

- Evolutionary models passed some tests
- But...early evolution is highly sensitive to initial conditions
- Need more observational tests

Fragmentation Products are Not Planets

Formation clues are detectable

- Composition
- Radius
- Luminosity

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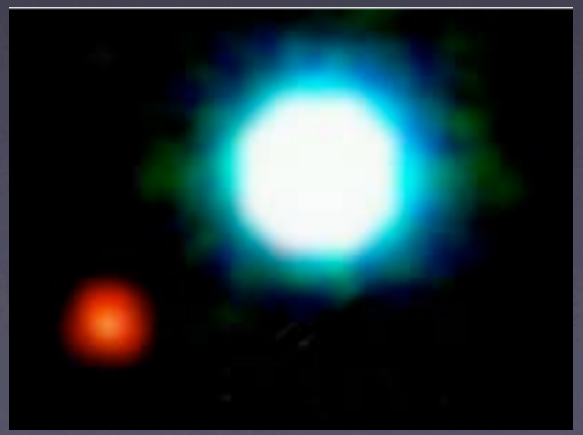

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Brown Dwarfs